

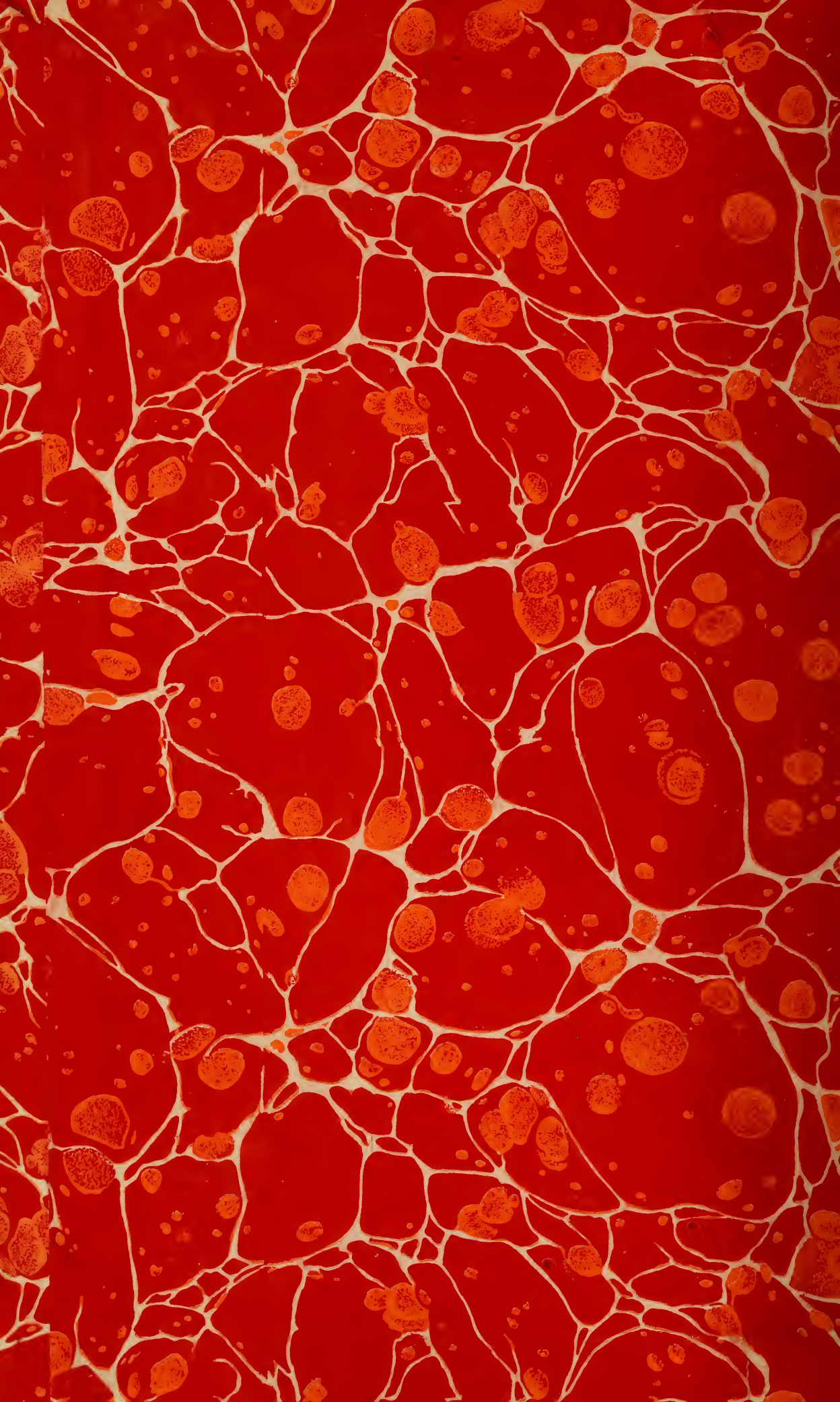
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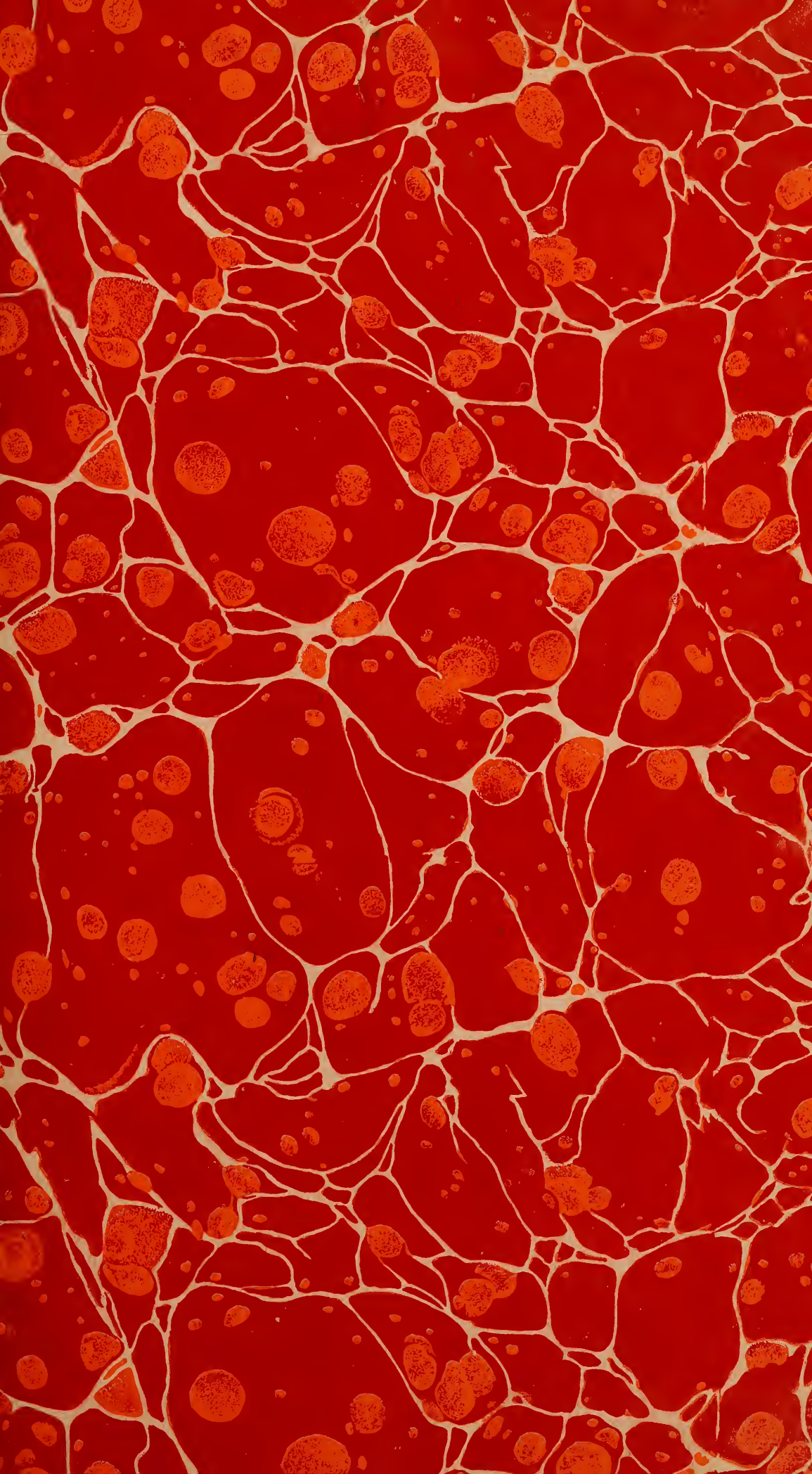
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THERMAL EXPANSION OF GASOLINES FROM 0° TO 30° C.¹

By C. S. Cragoe and E. E. Hill

ABSTRACT

Measurements are reported on the thermal expansion of 9 straight-run gasolines, 16 cracked gasolines, 3 motor benzols, and 5 benzol blends, from 0° to 30° C. The results indicate that the thermal expansion of cracked gasolines and benzol blends is systematically greater than the values based on straight-run gasolines given in National Standard Petroleum Oil Tables, Bureau of Standards Circular No. 154. The results also indicate that corrections for thermal expansion of present-day motor fuels, including straight-run gasolines, cracked gasolines, and benzol blends, can be made more accurately, in general, from a knowledge of their distillation curves than from gravity determinations.

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I. INTRODUCTION

The standard unit used most extensively in this country for determining quantities of gasoline and other petroleum products in commerce, is the gallon defined as 231 cubic inches of liquid at 60° F. In large-quantity shipments, tank cars for example, it is customary to determine the volume of gasoline at the existing temperature and to reduce the observed volume to the equivalent volume at 60° F. by the use of certain volume correction factors, such as those given in National Standard Petroleum Oil Tables, Bureau of Standards Circular No. 154.

The data on gasolines given in these tables are based upon measurements made prior to 1916 on the thermal expansion of straight-run gasolines, the only type of motor fuel in general use at that time. Approximately 50 per cent of the motor fuels now marketed consist of cracked gasolines and mixtures with benzol. Although the data given in Circular No. 154 were intended to be applicable only to straight-run gasolines, the data have been applied to cracked gasolines and benzol blends in the absence of definite information on these products. The work described in this paper was undertaken for the purpose of supplying experimental data on the thermal expansion of present-day motor fuels.

II. MATERIAL

The samples of gasolines and motor benzol used in this investigation, the information relating to their sources and the cracking processes used, were supplied for the most part by various oil companies through the courtesy of the American Petroleum Institute. A few of the gasoline samples were of unknown origin, having been submitted to the bureau for special tests.

¹ This paper contains results obtained in an investigation of the "Thermodynamic Properties of Petroleum Hydrocarbons" listed as Project No. 38 of the American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the institute with the cooperation of the Central Petroleum Committee of the National Research Council.

Many of the cracked gasolines were not intended to be strictly representative of the marketed products, since some of the samples submitted were taken directly from the cracking units and other samples had been treated to remove certain undesirable constituents but had not been blended with natural gasoline. It is assumed, however, that the thermal expansion data herein reported are reasonably representative of the expansion of motor fuels in general.

III. APPARATUS AND METHODS

The apparatus and methods used in this work are essentially the same as those previously described in detail in publications² of this bureau.

The method of hydrostatic weighing was employed in most of the measurements. A sinker was weighed in the sample under investigation and the density of the sample was calculated from the known external volume of the sinker and the difference between its weight in vacuo and when immersed in the sample.

The familiar picnometer method was used with a few of the more volatile samples because the excessive evaporation loss at the higher temperatures limited very materially the accuracy attainable by the sinker method.

The thermostated bath used consists of a large Dewar flask which is equipped with a refrigerating brine coil, an electric heater and a mechanical stirring device. Two mercury-in-glass thermometers, which had been calibrated at this bureau, were used in all of the measurements.

IV. PROCEDURE AND CALCULATION

The density of each gasoline was determined at three temperatures, approximately 0°, 15.56°, and 30° C. Measurements were then repeated in the reverse order on another sample of the same material. An illustration of the quantities actually observed and the method of calculating the results is given in Table 1, which is typical of many such record sheets.

A sample of gasoline was placed in a special glass tube and immersed in the bath. The temperature of the bath was then brought to the desired point and maintained constant for about 20 minutes before observations were begun. The rate of cooling obtainable with the brine system employed was considerably less than the rate used in heating electrically. Thus, the second sample was at the higher temperatures for a longer time, affording greater opportunity for loss by evaporation. As a consequence, the observed density at the next lower temperature was somewhat too large and the apparent change in density of the second sample was found to be larger, in general, than that obtained on the first sample. Since the effect of evaporation loss is in the opposite direction in the case of the first sample, the mean of the four values obtained as shown in Table 1 was taken as the average change in density per degree. The average coefficient of expansion was calculated from this value by means of the relation

$$\text{Coefficient of expansion} = \frac{1}{V_{15.56}} \frac{\Delta V}{\Delta T} = - \frac{1}{D_{15.56}} \frac{\Delta D}{\Delta T}$$

² Bureau of Standards Bulletin, vol. 9, p. 371; 1913; and B. S. Tech. Paper No. 77.

TABLE 1.—Sample records of observations and calculation of density by method of hydrostatic weighing

(Sample, cracked gasoline from California)

FIRST SAMPLE

Observed temperature, thermometer No.—	Corrections to thermometers		Corrected temperature		Mean temperature t'	Balance reading	Apparent weight of sinker in liquid	Buoyancy correction on weights	True weight of sinker in liquid	Weight of displaced liquid	Volume of sinker at temperature t'	Density of liquid at $t'/4^{\circ}\text{C}$.	Correction to integral degrees	Density of liquid at $t/4^{\circ}\text{C}$.	Integral temperature t	Average density change per $^{\circ}\text{C}$.
	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.		g	g	g	g	g	ml	g/ml	g/ml	g/ml	$^{\circ}\text{C}$.	g/ml $^{\circ}\text{C}$.
33557	33558															
	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	$^{\circ}\text{C}$.	g	g	g	g	g	ml	g/ml	g/ml	g/ml	0	0.000816
0.09	0.09	-0.07	0.02	0.03		24.1125	62.7821	-0.0087	62.7739	37.1874	47.68818	0.779803	+0.000016	0.779819		
.08	.08		.01	.02	0.02	24.1114	62.7826									
15.64	15.63	-0.07	15.57	15.59		23.4864	63.3751									
15.62	15.58		15.55	15.54	15.56	86.8615	63.3725	-	63.3650	36.5963	47.70619	.767118	.000000	.767118	15.56	0.000816
						23.4890	63.3738									
30.06	30.04	-0.07	29.99	29.98		22.9062	63.9248									
30.07	30.05		30.00	29.99	29.99	86.8310	63.9220	-	63.9146	36.0467	47.72266	.755337	-0.000008	.755329	30	0.000817
						22.9090	63.9234									

SECOND SAMPLE

30.05	30.03	-0.07	29.98	29.97		22.9170	63.9145									
30.07	30.05		30.00	29.99	29.99	86.8315	63.9119	-0.0038	63.9044	36.0569	47.72266	0.755551	-0.000008	0.755543	30	0.000834
15.61	15.57	-0.07	15.54	15.53		23.5125	63.3506									
15.58	15.55		15.51	15.51	15.52	86.8631	63.3491	-	63.3410	36.6203	47.70615	.767622	-0.000033	.767589	15.56	0.000825
	.07	-0.07	.01	.01		24.1435	62.7529									
.07	.06		0.00	0.00	0.00	86.8964	62.7524	-	62.7440	37.2173	47.68816	.780431	.000000	.780431	0	0.000823
						24.1440	62.7527								Mean =	

Mass of sinker No. 7 = 99.9613 g.

Buoyancy constant = 1.025.

Air density = 0.001163 g/ml.

V. RESULTS

A summary of the results obtained on straight-run and cracked gasolines is given in Table 2, together with corresponding values of density change and coefficient of expansion used in the compilation of Circular No. 154. Table 3 gives a similar summary of the results obtained on three motor benzols from different sources and several specially prepared mixtures of straight-run gasoline and motor benzol. The distillation data, given in Table 4, were obtained using A. S. T. M.^a Standard Method D86.

TABLE 2.—Data on thermal expansion of gasolines

STRAIGHT-RUN GASOLINES

Sample No.	Sample derived from oil from—	Cracking process used	Specific gravity at 60°/60° F.	Degrees A. P. I.	Density change per ° F.		Coefficient of expansion per ° F.	
					Observed	C. 154	Observed	C. 154
1	Pennsylvania		0.7494	57.32	0.00045	0.00045	0.00060	0.00060
2	West Virginia		.7273	63.06	.00046	.00047	.00063	.00064
3	do		.6950	72.10	.00049	.00049	.00070	.00071
4	Kansas		.7525	56.54	.00045	.00045	.00060	.00060
5	Oklahoma		.6970	71.51	.00050	.00049	.00072	.00071
6	Texas		.7488	57.47	.00046	.00045	.00061	.00060
7	California		.7581	55.15	.00046	.00044	.00061	.00058
8	do		.7618	54.24	.00046	.00044	.00061	.00058
9 ¹			.7841	48.96	.00042	.00042	.00054	.00053

LIQUID-PHASE CRACKED GASOLINES

10	Pennsylvania	Dubbs	0.7386	60.08	0.00048	0.00046	0.00064	0.00062
11 ²	do	Cross	.7417	59.28	.00047	.00045	.00063	.00061
12 ³	Mid-Continent	Holmes-Manley	.7415	59.33	.00047	.00045	.00063	.00061
13	do	Tank and tube	.7399	59.74	.00047	.00046	.00063	.00062
14 ⁴	{ Mixture from Oklahoma, Texas, Louisiana and Gulf Coast }	Cross	.7453	58.36	.00047	.00045	.00063	.00061
15 ⁵		do	.7537	56.24	.00046	.00044	.00062	.00059
16 ⁶	Panhandle	Dubbs	.7525	56.54	.00047	.00045	.00062	.00060
17 ⁴	Kansas	do	.7404	59.61	.00048	.00046	.00064	.00062
18 ⁴	Oklahoma	Cross	.7584	55.08	.00046	.00044	.00061	.00058
19 ³	do	Dubbs	.7230	64.21	.00048	.00047	.00067	.00065
20	Texas	Holmes-Manley	.7523	56.59	.00046	.00045	.00061	.00060
21 ⁶	California	Doherty	.7582	55.13	.00047	.00044	.00061	.00058
22	do	Cross	.7681	52.72	.00046	.00044	.00059	.00057

VAPOR-PHASE CRACKED GASOLINES

23	West Virginia	Gyro	0.7436	58.79	0.00047	0.00045	0.00064	0.00061
24 ⁷			.7769	50.63	.00047	.00043	.00060	.00055
25			.7797	49.98	.00046	.00042	.00059	.00054

¹ Mineral spirits used as a paint thinner and also as a damping liquid in aircraft compasses. (For specification, see B. S. Circular No. 98.)

² Before blending.

³ Treated and redistilled.

⁴ Direct from cracking unit.

⁵ After treating.

⁶ Before treating.

⁷ Cracking process used is described in National Petroleum News, vol. 18, p. 104; 1926.

^a Proceedings of the American Society for Testing Materials, vol. 26, p. 816; 1926.

TABLE 3.—Data on thermal expansion of motor benzols and gasoline-benzol blends

Sample No.	Percentage by volume		Specific gravity 60°/60° F.	De-grees A. P. I.	Density change per ° F.			Coefficient of expansion per ° F.		
	A	B			Observed	Calcu-lated ¹	Circular 154 ²	Observed	Calcu-lated ¹	Circu-lar 154 ²
4.....	0	³ 100	0.7525	56.54	0.00045	-----	0.00045	0.00060	-----	0.00060
26.....	10	90	.7647	53.54	.00046	0.00046	.00044	.00060	0.00060	.00057
27.....	25	75	.7825	49.33	.00048	.00048	.00041	.00061	.00061	.00053
30.....	50	50	.8138	42.37	.00051	.00051	.00040	.00063	.00063	.00049
33.....	⁴ 100	0	.8824	28.86	.00058	-----	.00037	.00066	-----	.00042
2.....	0	⁵ 100	.7275	63.00	.00046	-----	.00047	.00063	-----	.00064
29.....	25	75	.7640	53.71	.00048	.00048	.00044	.00063	.00063	.00057
30.....	50	50	.8005	45.26	.00050	.00051	.00040	.00063	.00064	.00050
31.....	⁶ 100	0	.8793	29.42	.00056	-----	.00037	.00064	-----	.00042
32.....	⁷ 100	0	.8772	29.81	.00057	-----	.00037	.00065	-----	.00042

¹ See Section VII for method of calculation.
² These values are given here for the purpose of comparison only. The data in Circular No. 154 were not intended to be applicable to motor benzol or to gasoline-benzol blends.
³ Straight-run gasoline obtained from Kansas crude.
⁴ Motor benzol obtained from Gary, Ind.
⁵ Straight-run gasoline obtained from West Virginia crude.
⁶ Motor benzol obtained from Lackawanna, Pa.
⁷ Motor benzol obtained from Woodlawn, Pa.

TABLE 4.—Distillation data
STRAIGHT-RUN GASOLINES

Sample No.	Temperature in ° C. at various percentages distilled—											Resi- due	Loss	Aver age vola- tility
	Ini- tial	10	20	30	40	50	60	70	80	90	End			
1.....	55	87	100	112	123	134	146	160	174	190	218	Per cent 1.2	Per cent 1.2	° C. 136
2.....	40	70	85	98	110	122	134	148	165	185	216	1.4	1.3	124
3.....	53	-----	75	-----	-----	79	-----	-----	-----	110	163	1.8	0.4	¹ 87
4.....	48	80	96	110	122	134	146	159	173	189	206	1.2	1.6	132
5.....	58	-----	68	-----	-----	72	-----	-----	-----	85	106	0.5	0.5	¹ 75
6.....	50	74	87	100	113	125	138	152	167	183	204	1.2	1.4	125
7.....	50	78	96	109	122	134	148	162	178	198	220	1.4	1.1	135
8.....	52	78	95	109	122	135	149	164	180	200	220	1.2	0.8	136
9.....	158	162	165	168	171	174	177	180	184	193	210	1.7	0.3	176

CRACKED GASOLINES

10.....	35	60	74	87	102	118	134	150	169	189	215	1.0	2.2	119
11.....	40	65	79	92	116	130	146	163	180	196	210	1.1	2.1	128
12.....	40	66	85	99	112	123	135	150	166	184	218	1.2	1.8	121
13.....	39	65	83	98	112	126	140	155	170	186	196	0.9	1.7	123
14.....	28	56	76	94	111	127	144	162	180	198	212	1.0	4.6	119
15.....	40	68	88	105	121	135	150	165	180	196	207	0.9	1.8	130
16.....	40	66	85	102	118	132	147	162	178	196	219	1.1	1.7	129
17.....	29	56	72	85	98	111	125	141	160	182	213	1.3	2.7	112
18.....	42	67	86	103	118	133	149	166	184	203	217	1.2	1.5	132
19.....	40	60	74	86	98	109	120	132	144	156	169	1.1	1.4	107
20.....	48	73	93	109	124	138	152	167	182	197	212	1.6	1.4	134
21.....	38	63	82	99	114	129	145	152	170	190	209	1.2	1.8	124
22.....	40	69	89	107	124	140	157	174	192	202	222	1.2	1.8	133

Estimated the 10 per cent point from curve.

TABLE 4.—Distillation data—Continued.

GASOLINE-BENZOL BLENDS

Sample No.	Temperature in ° C. at various percentages distilled—											Resi- due	Loss	Aver- age vola- tility
	Ini- tial	10	20	30	40	50	60	70	80	90	End			
26.....	65	83	92	102	116	129	143	158	170	188	206	Per cent 0.9	Per cent 1.4	° C. 131
27.....	69	82	88	94	101	113	127	146	166	184	200	0.9	1.4	125
28.....	74	81	84	87	90	95	102	120	141	174	201	1.0	1.5	114
29.....	66	80	87	94	102	112	123	137	155	180	216	1.3	0.9	122
30.....	74	84	88	91	95	100	110	124	146	175	208	1.1	0.9	118

MOTOR BENZOLS

31.....	82	85	86	87	88	90	92	95	103	119	146	1.0	0.7	98
32.....	75	82	85	85	85	86	87	89	96	118	144	0.6	0.9	95
33.....	79	81	82	82	83	84	84	85	88	100	145	0.4	1.0	88

VI. VOLUME AND TEMPERATURE CHANGES ON MIXING GASOLINE AND BENZOL

It is well known that appreciable changes in volume and temperature accompany the mixing of certain liquids, a familiar example being water and alcohol. Such changes are usually considered to be very small, however, in the blending of petroleum oils.

In the preparation of definite mixtures of gasoline and motor benzol relatively large temperature changes were noted and it appeared to be of some interest to measure with moderate accuracy the temperature and volume changes on mixing. Equal volumes of the two liquids were measured in separate calibrated flasks at approximately 25° C. The two liquids were then transferred to a larger flask of twice the capacity and the temperature observed after thorough mixing. The mixture was brought to the initial temperature and the increase in volume on mixing was observed. The results obtained are recorded in Table 5.

TABLE 5.—Volume and temperature changes on mixing

Sam- ple No.	Material	Sample obtained from—	Temperature		Tempera- ture change	Expansion	Per- centage A by volume
			Before mixing	After mixing			
4	A Gasoline.....	Kansas crude.....	° C	° C	° C	Per cent	
33	B Benzol.....	Gary, Ind.....	25.2	21.6	−3.6	+0.33	50
2	A Gasoline.....	West Virginia crude.....	24.9	21.5	−3.4	+ .36	50
31	B Benzol.....	Lackawanna, Pa.....	25.0	21.9	−3.1	-----	50
8	A Gasoline.....	California.....					
32	B Benzol.....	Woodlawn, Pa.....					

TABLE 5.—Volume and temperature changes on mixing—Continued

For the purpose of comparison, the following data on pure substances are quoted from Sidney Young, Fractional Distillation, p. 40 and p. 42, MacMillan & Co. (Ltd.), London, 1903

Sample No.	Material	Sample obtained from—	Temperature		Temperature change	Expansion	Percentage A molal
			Before mixing	After mixing			
	A Benzene....	-----	-----	-----	°C	Per cent	
	B <i>n</i> -hexane....	-----	-----	-----	-4.7	+0.52	50
	A <i>n</i> -hexane....	-----	-----	-----			
	B <i>n</i> -octane....	-----	-----	-----	+.06	-.053	50
	A Water.....	-----	-----	-----			
	B Ethyl alcohol.	-----	-----	-----	+2.95	-2.56	40

The data obtained by Sidney Young on mixtures of benzene and *n*-hexane, quoted in this table, show changes in the same direction and of the same order of magnitude while the changes observed with mixtures of *n*-hexane—*n*-octane, and water-alcohol are in the opposite direction and of a different order of magnitude.

VII. CALCULATION OF EXPANSION OF BENZOL BLENDS BY MIXTURE RULES

Since the expansion on mixing gasoline and benzol is relatively small, approximate values for the density of known mixtures at a given temperature may be calculated from the relation

$$100 D_m = x D_b + (100 - x) D_g$$

in which the subscripts refer to mixture, benzol, and gasoline, respectively, D =density, and x =per cent benzol, by volume. By substituting in this relation, the general equation

$$D_t = D_o - \alpha (t - t_o)$$

in which t =temperature, α =change in density per degree at t_o , and the subscript zero refers to any convenient reference temperature, it follows that

$$100 \alpha_m = x \alpha_b + (100 - x) \alpha_g$$

Similarly, from the relation between coefficient of expansion and change in density per degree,

$$A = \frac{1}{V_o} \frac{dV}{dt} = - \frac{1}{D_o} \frac{dD}{dt} = \frac{\alpha}{D_o}$$

it follows that

$$100 A_m D_m = x A_b D_b + (100 - x) A_g D_g$$

Values calculated from these mixture rules are in good agreement with the observed values, as shown in Table 3. These mixture rules were used to calculate the tables on thermal expansion of gasoline-benzol mixtures and also the corrections to readings of hydrometers in such mixtures, given in Bureau of Standards, Miscellaneous Publica-

tion No. 97, Thermal Properties of Petroleum Products. The data herein reported on such mixtures constitute the experimental basis for those tables, which give values for mixtures containing 25 and 50 per cent benzol. The practical usefulness of the tables is rather limited, however, because the benzol content must be known in order to make accurate interpolation of the tabulated data. A more useful and accurate means of making corrections for thermal expansion is given later.

VIII. COMPARISON WITH PREVIOUS WORK

Table 6 gives data obtained by previous observers on presumably straight-run petroleum products which come within the gravity range covered in the present work. Figure 1 gives a graphical comparison of these data with the present results, Circular No. 154, and most of the available data on pure hydrocarbons of comparable gravity and volatility.

TABLE 6.—*Data of previous observers*

DATA OBTAINED BY H. W. BEARCE AND E. L. PEPPER, B. S. TECH. PAPER NO. 77; 1916

Nature of oil	Derived from oil from—	Specific gravity at 60°/60° F.	Degrees A. P. I.	Density change per ° F.		Coefficient of expansion per ° F.	
				Observed	Circular 154	Observed	Circular 154
Naphtha.....		0.6872	74.4	0.00049	0.00049	0.00072	0.00072
Gasoline.....		.7066	68.7	.00048	.00048	.00068	.00068
Naphtha.....		.7108	67.6	.00049	.00048	.00069	.00068
Gasoline.....	Texas.....	.7383	60.2	.00047	.00046	.00064	.00062
	Pennsylvania.....	.7394	59.9	.00046	.00046	.00062	.00062
	California.....	.7407	59.5	.00048	.00046	.00065	.00062
Benzine.....	do.....	.7517	56.7	.00047	.00044	.00063	.00059
Naphtha.....	Indiana.....	.7536	56.3	.00046	.00044	.00061	.00059
Engine distillate.....	California.....	.7762	50.8	.00044	.00043	.00057	.00055
Gasoline.....	Oklahoma.....	.7840	49.0	.00042	.00042	.00054	.00054

DATA OBTAINED BY ZEITFUCHS, INDUSTRIAL & ENGINEERING CHEMISTRY, VOL 17, P. 1280; 1925

Gasoline.....	California.....	0.7662	53.2	0.00048	0.00044	0.00062	0.00057
Crude naphtha.....	do.....	.7886	47.9	.00046	.00042	.00058	.00053
Engine distillate.....	do.....	.7991	45.6	.00047	.00041	.00059	.00051

Data are included on the following compounds: Paraffin series, normal compounds from C_7H_{16} to $C_{16}H_{34}$; naphthene series, the following monocyclics, cyclopentane, cyclohexane, cycloheptane and cyclooctane and the following substituted monocyclics, methylcyclopentane, methylcyclohexane, ethylcyclobutane, 1-1 and 1-4 dimethylcyclohexane; aromatic series, benzene, toluene, *m*-xylene, and *n*-propylbenzene. The data on these compounds were taken from the following sources: International Critical Tables, Vol. III; Engler-Hofer, Das Erdol. Vol. I; and Beilstein Vol. V. While there may be some question relative to the accuracy of the data on these hydrocarbons and also to their purity, the data serve a useful purpose here, however, to indicate trends.

The data presented in Figure 1 indicate that the results obtained on motor fuels are consistent, in general, with available information on their composition. Straight-run gasolines from eastern and mid-

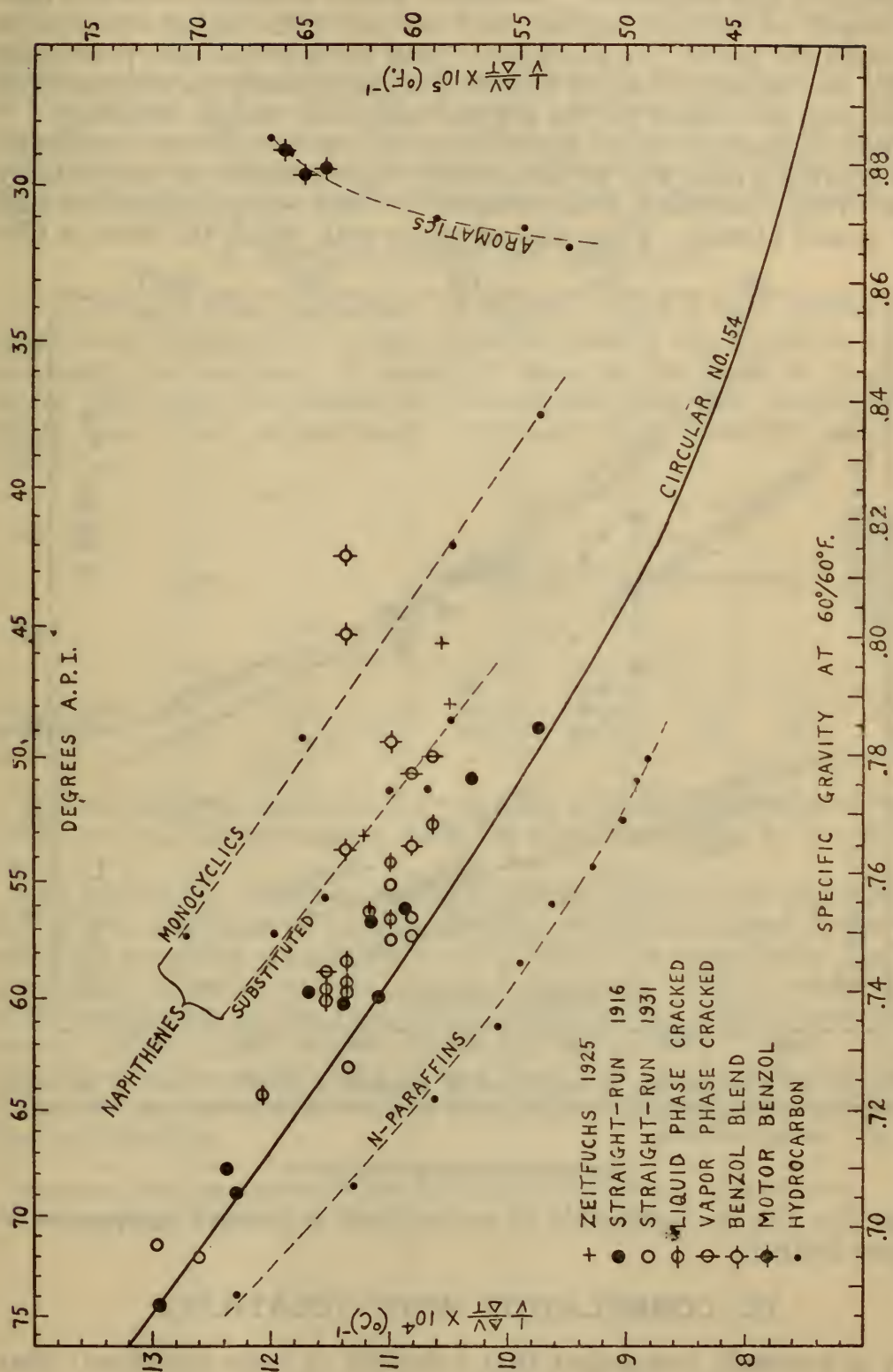


FIGURE 1—Comparison of coefficient of expansion at 60° F. of motor fuels and pure hydrocarbons on the basis of gravity

continent crudes, for example, are known to be rich in paraffin series hydrocarbons, while straight-run gasolines from many California crudes and also cracked gasolines are known to be relatively richer in naphthenes and aromatics. Similarly, motor benzol is known to consist largely of benzene together with several of the higher members of the aromatic series. In accordance with the mixture rule, previously given, the values for benzol blends lie approximately on straight lines connecting the values for the original materials used in blending.

There appears to be no simple relation between thermal expansion and gravity which will be adequately representative of present-day motor fuels, including both straight-run and cracked gasolines and also benzol blends. Thus, the accuracy with which the data in Cir-

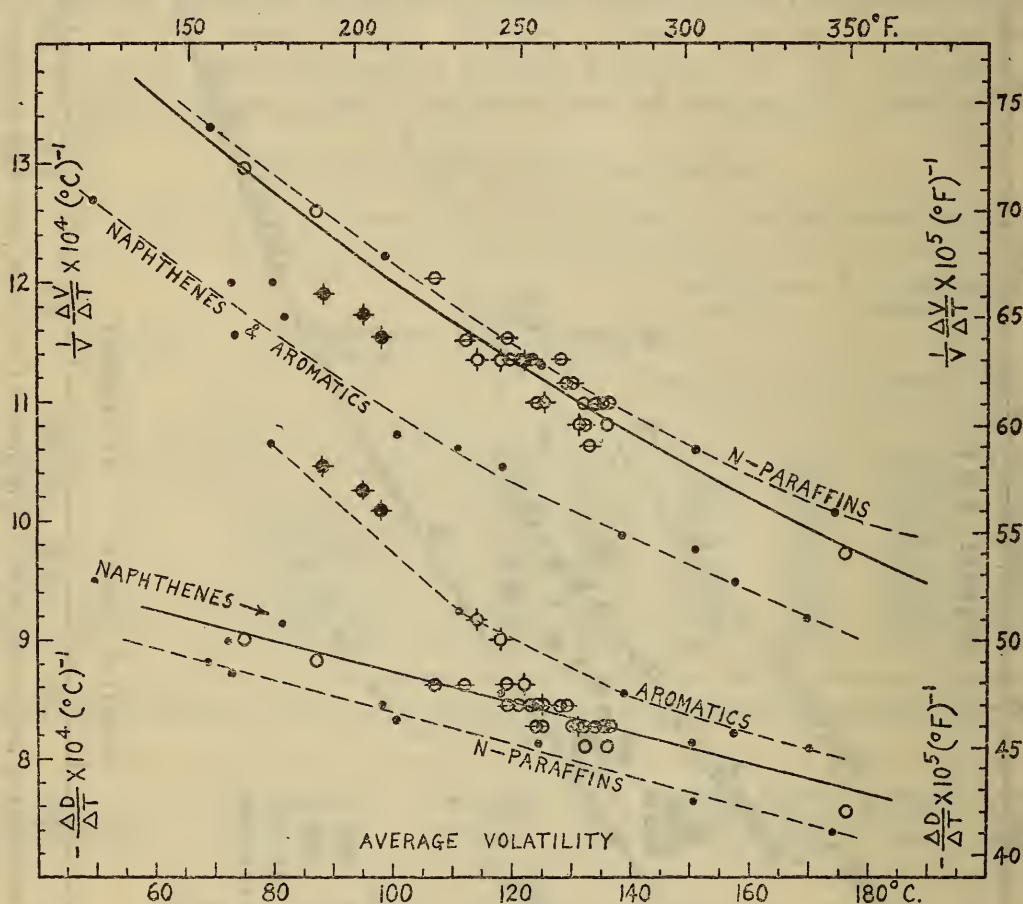


FIGURE 2.—Comparison of coefficient of expansion at 60° F. and of density change with temperature of motor fuels and pure hydrocarbons on the basis of "average volatility"

Symbols are the same as in Figure 1.

cular No. 154 are applicable to motor fuels in general appears to be rather limited.

IX. CORRELATION WITH VOLATILITY

It is generally recognized that volatility is more significant than gravity as an index of the suitability of a gasoline for a particular use. Most specifications, for example, require a distillation test, whereas a gravity determination is not required. It appears also from the results reported herein that "average volatility" serves much better than gravity as an index of thermal expansion. "Average volatility"

as used here is defined as the average of the temperatures at which 10, 50, and 90 per cent is evaporated. (Per cent evaporated = per cent distilled plus evaporation loss.)

As shown in Figure 2, in which the symbols are the same as those used in Figure 1, the range in the values of the coefficient of expansion and also the change in density per degree, for hydrocarbons of comparable normal boiling points, and consequently for mixtures of them as represented by motor fuels, is much narrower than in the corresponding case of Figure 1. Thus, when put on this basis there appear to be little or no systematic differences between straight-run gasolines, cracked gasolines, and blends containing up to 50 per cent benzol.

X. APPLICATION OF RESULTS

It is evident from inspection of Figures 1 and 2 that corrections for thermal expansion of motor fuels in general can be made more accurately on the basis of volatility than on the basis of gravity. Motor fuels may be divided for convenience into two classes, on a utility basis which is practically equivalent to a volatility basis, as follows:

Class	Range of "average volatility"		Mean volatility		Corresponding average coefficient of expansion at 60° F
	° C.	° F.	° C.	° F.	per ° F.
Aviation gasoline.....	80-110	176-230	95	203	0.00068
Motor gasoline.....	110-140	230-284	125	257	.00062

The values given above for the volatility of these two classes of fuels are in substantial agreement with the results obtained in numerous surveys.⁴

The coefficients of expansion given above appear to be representative of the expansion of gasoline coming within the stated ranges of volatility to about the accuracy with which the correlation (fig. 2) appears to be valid, namely, about 5 per cent. This is equivalent to an uncertainty of less than 0.07 per cent in the volume correction factors for the usual temperature range 40° to 80°F. Since this is equivalent to an uncertainty of less than 1°F. in the determination of the average temperature of the fuel, it is not very serious in practical applications.

⁴ Semiannual Motor Gasoline Surveys, 1920-1931, Bureau of Mines, Reports of Investigations.

TABLE 7—Volume correction factors for gasolines

Observed tempera- ture, ° F.	Volume at 60° F. occu- pled by unit volume at observed temper- ature		Observed tempera- ture, ° F.	Volume at 60° F. occu- pled by unit volume at observed temper- ature	
	Aviation gasolines	Motor gasolines		Aviation gasolines	Motor gasolines
	“Average volatility”			“Average volatility”	
	80°-110° C. 176°-230° F.	110°-140° C. 230°-284° F.		80°-110° C. 176°-230° F.	110°-140° C. 230°-284° F.
0	1.0407	1.0370	60	1.0000	1.0000
1	1.0400	1.0364	61	.9993	.9994
2	1.0393	1.0358	62	.9986	.9988
3	1.0387	1.0351	63	.9980	.9981
4	1.0380	1.0345	64	.9973	.9975
5	1.0373	1.0339	65	.9966	.9969
6	1.0366	1.0333	66	.9959	.9963
7	1.0359	1.0327	67	.9952	.9957
8	1.0353	1.0321	68	.9946	.9950
9	1.0346	1.0315	69	.9939	.9944
10	1.0339	1.0309	70	.9932	.9938
11	1.0332	1.0303	71	.9925	.9932
12	1.0326	1.0297	72	.9918	.9926
13	1.0319	1.0290	73	.9911	.9919
14	1.0313	1.0284	74	.9904	.9913
15	1.0306	1.0278	75	.9897	.9907
16	1.0299	1.0272	76	.9890	.9901
17	1.0292	1.0266	77	.9883	.9895
18	1.0286	1.0259	78	.9877	.9888
19	1.0279	1.0253	79	.9870	.9882
20	1.0272	1.0247	80	.9863	.9876
21	1.0265	1.0241	81	.9856	.9870
22	1.0258	1.0235	82	.9849	.9863
23	1.0252	1.0229	83	.9842	.9857
24	1.0245	1.0223	84	.9835	.9850
25	1.0238	1.0217	85	.9828	.9844
26	1.0231	1.0211	86	.9821	.9838
27	1.0225	1.0205	87	.9814	.9832
28	1.0218	1.0198	88	.9808	.9825
29	1.0212	1.0192	89	.9801	.9819
30	1.0205	1.0186	90	.9794	.9813
31	1.0198	1.0180	91	.9787	.9807
32	1.0191	1.0174	92	.9780	.9801
33	1.0184	1.0167	93	.9774	.9794
34	1.0177	1.0161	94	.9767	.9788
35	1.0170	1.0155	95	.9760	.9782
36	1.0163	1.0149	96	.9753	.9776
37	1.0156	1.0143	97	.9746	.9770
38	1.0150	1.0136	98	.9739	.9763
39	1.0143	1.0130	99	.9732	.9757
40	1.0136	1.0124	100	.9725	.9751
41	1.0129	1.0118	101	.9718	.9745
42	1.0123	1.0112	102	.9711	.9739
43	1.0116	1.0105	103	.9705	.9732
44	1.0110	1.0099	104	.9698	.9726
45	1.0103	1.0093	105	.9691	.9720
46	1.0096	1.0087	106	.9684	.9714
47	1.0089	1.0081	107	.9677	.9708
48	1.0082	1.0074	108	.9670	.9701
49	1.0075	1.0068	109	.9663	.9695
50	1.0068	1.0062	110	.9656	.9689
51	1.0061	1.0056	111	.9649	.9683
52	1.0054	1.0050	112	.9642	.9676
53	1.0048	1.0043	113	.9635	.9670
54	1.0041	1.0037	114	.9628	.9663
55	1.0034	1.0031	115	.9621	.9657
56	1.0027	1.0025	116	.9614	.9651
57	1.0020	1.0019	117	.9607	.9645
58	1.0014	1.0012	118	.9601	.9638
59	1.0007	1.0006	119	.9594	.9632
60	1.0000	1.0000	120	.9587	.9626

Volume correction factors, based upon the above coefficients of expansion, are given in Table 7. The data in this table furnish a convenient and accurate means for reducing volumes of gasoline to the basis of 60° F. The factors given in this table are in the form of "multipliers"; that is, the observed volume of gasoline at the observed temperature, multiplied by the corresponding correction factor in the table, equals the volume at 60° F. For example, if the "average volatility" (which corresponds approximately to the 50 per cent point on the distillation curve) of the gasoline is within the range 230° to 284° F. (110° to 140° C.) and the observed volume at 90° F. is 10,000 gallons, then the volume at 60° F. equals $10,000 \times 0.9813 = 9,813$ gallons.

WASHINGTON, September 15, 1931.

